

RESTORATION OF PARITY SYMMETRY THROUGH PRESYMMETRY

ERNESTO A. MATUTE

*Departamento de Física, Universidad de Santiago de Chile,
 Usach, Casilla 307 – Correo 2, Santiago, Chile
 ernesto.matute@usach.cl*

Presymmetry, the hidden symmetry underlying the charge and generational patterns of quarks and leptons, is utilized for repairing the left–right asymmetry of the standard model with Dirac neutrinos. It is shown that the restoration of parity is consequent with an indispensable left–right symmetric residual presymmetry. Thus, presymmetry substantiates left–right symmetry and the experimental search for the latter is the test of the former, with the nature of neutrinos as a crucial feature that can distinguish the left–right symmetry alone and its combination with presymmetry. This phenomenological implication is in accordance with the fact that Majorana neutrinos are usually demanded in the first case, but forbidden in the second.

Keywords: Parity symmetry; charge symmetry; flavor symmetry; presymmetry.

PACS Nos.: 11.30.Er, 11.30.Hv, 11.30.Ly, 12.60.Cn

1. Introduction

The phenomenological success of the standard model (SM) of particle physics based on the gauge group $SU(3)_c \times SU(2)_L \times U(1)_Y$ is moderated by a number of problems. There is no logical sense for the complete asymmetry between left and right in the weak sector and no explanation for the charge symmetry between quarks and leptons. It also offers no reason for the existence of fermion family copies and no prediction for their numbers. Faced with these troubles, many theoretical ideas have been advanced beyond the SM.

The minimal extension of the SM which repairs its left–right (LR) asymmetry is in the LR symmetric models (LRSM) with gauge group $SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$, where an interchange symmetry between the left and right sectors is assumed.¹ The other popular choice to rectify the LR asymmetry of the SM is held by the mirror matter models based on the gauge group $G_L \times G_R$, where $G_{L,R} = SU(3)_c \times SU(2)_{L,R} \times U(1)_Y$, with equal gauge coupling constants for the symmetric sectors.^{2–8} However, none of these extended chiral models with LR symmetry finds the solutions to the quark–lepton $U(1)$ -charge symmetry and family problems.

These issues indeed have been addressed within the SM itself via presymmetry, an electroweak symmetry between quarks and leptons with Dirac neutrinos hidden by the nontrivial topology of weak gauge fields.^{9,10} Our purpose in this letter is to consider the possible LR symmetric extensions of presymmetry beyond the SM in order to have a testable residual presymmetry with LR symmetry as in the LRSM and mirror matter models, and therefore give unified answers to the important fundamental questions on charge symmetries, triplication of families and LR asymmetry left open by the SM. In Sec. 2, we refer to presymmetry within the context of the SM, emphasizing relevant points to this work. In Sec. 3, we deal with the LR symmetric extension of presymmetry leading to the LR symmetry embedded in the LRSM, distinguishing phenomenologically the conventional models and those supplemented with presymmetry. The alternative residual presymmetry connected with mirror matter models was put forth in Ref. 11 and the essential results are confronted here with those related to the LRSM. The conclusions are presented in Sec. 4.

2. On Presymmetry in the SM

The basis of presymmetry is an electroweak quark–lepton symmetry within the SM. For a weak hypercharge defined in terms of the electric charge and the third component of weak isospin as $Q = T_{3L} + Y/2$, such a symmetry can be read in the following chiral relations^{9,10}:

$$Y(q_{L,R}) = Y(\ell_{L,R}) + \Delta Y(\ell_{L,R}), \quad Y(\ell_{L,R}) = Y(q_{L,R}) + \Delta Y(q_{L,R}), \quad (1)$$

where ΔY involves the baryon and lepton numbers according to

$$\Delta Y = -\frac{4}{3}(3B - L) \quad (2)$$

and $q_{L,R}$ and $\ell_{L,R}$ refer to the quark and lepton weak partners in L -doublets and R -singlets of $SU(2)_L$ within each of the three families of the SM, right-handed neutrinos of $Y = 0$ included; parity symmetry is broken in $SU(2)_L$ and $U(1)_Y$. The hypercharge normalization can change the value of the global fractional part ΔY , with the 3 attributable to the number of quark colors, but not the underlying charge symmetry.

Presymmetry emerges from the correspondence of quark and lepton charges if the global piece is kept away, easily perceived in Eq. (1). This quark–lepton symmetric pattern makes sense only for Dirac neutrinos.

To understand the charge symmetry and the charge dequantization hidden in Eq. (1), the prequark (prelepton) states denoted by \hat{q} ($\hat{\ell}$) are introduced. They are defined by the quantum numbers of quarks (leptons), except charge values. Hypercharges of prequarks (preleptons) are the same as their lepton (quark) weak partners. From Eq. (1) one is led to

$$Y(q_{L,R}) = Y(\hat{q}_{L,R}) + \Delta Y(\hat{q}_{L,R}), \quad Y(\ell_{L,R}) = Y(\hat{\ell}_{L,R}) + \Delta Y(\hat{\ell}_{L,R}), \quad (3)$$

where now

$$\Delta Y = -\frac{4}{3}(B - 3L). \quad (4)$$

Here the combination $B - 3L$ is instead of $3B - L$ because prequarks (preleptons) are entities that take the lepton (quark) hypercharge values. This implies $B(\hat{q}_{L,R}) = -1$ and $L(\hat{\ell}_{L,R}) = -1/3$, with the 3 attributable to the number of families.¹⁰

The charge symmetry in Eq. (1) and the charge dequantization in Eq. (3) are kept up with $3B - L$ and $B - 3L$ as ungauged global symmetries, quarks and leptons as the ultimate constituents of ordinary matter, and prequarks and preleptons as their basic bare states.

The hidden quark–lepton charge symmetry is implemented under the premise that the global piece of hypercharge has a weak topological character. Since any weak topological feature cannot have observable effects at the zero-temperature scale because of the smallness of the weak coupling, the charge structure reflected in Eq. (3) does not apply to quarks, but to new states referred to as topological quarks. Nonetheless the assignments of topological quarks to the gauge groups of the SM are the same of quarks. The electroweak presymmetry is indeed between topological quarks and preleptons having nontrivial charge structure, and between prequarks and leptons with no charge structure.

The interactions of prequarks (topological quarks) and leptons (preleptons) with the gauge and Higgs fields are assumed to be described by the same Lagrangian of the SM with quarks and leptons except hypercharge couplings and inclusion of Dirac neutrinos.

The nonstandard fermionic hypercharges generate the $U(1)[SU(2)]^2$ and $[U(1)]^3$ gauge anomalies in the couplings by fermion triangle loops of three currents associated with the chiral $U(1)$ and $SU(2)$ gauge symmetries. Their cancellations require a counterterm which includes topological currents or Chern–Simons classes related to the $U(1)$ and $SU(2)$ gauge groups, leading to the appearance of nontrivial topological winding numbers in the case of pure gauge fields $SU(2)$. Vacuum states labelled by different topological numbers are then tunneled by $SU(2)$ instantons carrying topological charges, which are responsible for the transitions and charge shifts from the nonstandard to standard fermions. Explicitly, in the presymmetric scenario of prequarks and leptons, for instance, each prequark hypercharge is equally modified by an amount set down as^{9,10}:

$$\Delta Y(\hat{q}_{L,R}) = -\frac{n}{3}(B - 3L)(\hat{q}_{L,R}), \quad (5)$$

where n is the topological charge of a weak $SU(2)$ instanton.

The anomaly cancellation and removal of the related counterterm, needed for gauge invariance and renormalizability of the theory, fix the index $n = 4$ in Eq. (5). This value matches Eq. (5) to (4) and is independent of the normalization used for hypercharge.¹¹

3. LR Symmetry as a Residual Presymmetry

The transitions from prequarks to topological quarks and from the latter to quarks through weak SU(2) instantons do not take place in the real world because, as argued in Ref. 11, prequarks and topological quarks, in addition to preleptons, are not real dynamical entities. They are bare prestates of quarks and leptons seen as mathematical entities out of which the actual particle states are built up. In a sense, such transitions are truncated by the extreme smallness of the instanton transition probability.

In spite of the fact that presymmetry is a hidden electroweak symmetry within the system of quarks and leptons, the scheme defines a theoretical framework with several physical implications¹⁰: it explains the fractional charge of quarks and the quark-lepton charge relations, it correlates the number of fermion generations with the number of quark colors, and it predicts the Dirac character of neutrinos. Also, it accounts for the topological charge conservation in quantum flavor dynamics, and it explains charge quantization and the no observation of fractionally charged hadrons.

Yet, there is nothing physically new at the level of quarks and leptons, so that the quark-lepton hidden presymmetry cannot be tested. In this case, it is impossible to either verify or falsify the underlying symmetric scheme, which is really difficult to accept. These are strong motivations for a verifiable residual presymmetry via partial or complete duplication of standard particles, in a LR symmetric manner to have unified answers to questions left open by the SM.

The basic premise is that presymmetry between quarks and leptons is LR symmetric, doubling the weak gauge group of the SM in the case of a minimal extension, just as in the LRSM. They are arranged in left- and right-handed doublets of SU(2)_L and SU(2)_R, respectively¹: $q_{L,R} = (u, d)_{L,R}$ and $\ell_{L,R} = (\nu, e)_{L,R}$, within each of their three families. The formula for the electric charge is $Q = T_{3L} + T_{3R} + (B - L)/2$ and the quark-lepton charge symmetry is as in Eq. (1) with $B - L$ instead of Y ; it is the gauged combination of $3B - L$ and $B - 3L$ global symmetries.

The scheme to understand this charge symmetry and the charge dequantization like in Eq. (3) is similar to that in the SM, described in Sec. 2. In the scenario of symmetric prequarks and leptons, there are two U(1)[SU(2)]² gauge anomalies and the charge shifts of Eq. (5) from prequarks to topological quarks are now

$$\Delta(B - L)(\hat{q}_{L,R}) = -\frac{n}{3} (B - 3L)(\hat{q}_{L,R}), \quad (6)$$

where $n = n_L - n_R$, with $n_{L,R}$ being the topological charge of the SU(2)_{L,R} instanton; the change of sign is due to the axial character of the anomaly. The requirements of anomaly cancellation, removal of the corresponding counterterm and LR symmetry lead to $n_L = -n_R = 2$, making Eq. (6) equal to (4) with $B - L$ in place of Y . For simplicity, we indicate this hidden charge symmetry relating quark and lepton doublets as

$$q_L \leftrightarrow \ell_L, \quad q_R \leftrightarrow \ell_R. \quad (7)$$

Similarly, due to the vectorial character of B and L , there is the hidden presymmetry given by

$$q_L \leftrightarrow \ell_R, \quad q_R \leftrightarrow \ell_L, \quad (8)$$

with symmetry between the $SU(2)_L$ and $SU(2)_R$ gauge and Higgs fields of equal couplings, and the underlying topological-charge symmetry $n_L = -n_R = 2$.

These hidden Z_2 symmetries introduce LR symmetry in presymmetry, leading to the usual LR symmetry

$$q_L \leftrightarrow q_R, \quad \ell_L \leftrightarrow \ell_R, \quad (9)$$

which remains exact after the underlying charge normalization with the topological-charge correspondence $n_L \leftrightarrow -n_R$. Thus, parity is restored and the LR symmetry itself embedded in the LRSM becomes the required testable residual presymmetry.

An alternative residual presymmetry manifested as a LR symmetry is provided by mirror matter models, put forth in Ref. 11 and included here for completeness. Other motivations to consider this possibility are to extend presymmetry from matter to forces and from the electroweak to the strong sector, doubling the particle spectrum completely.

On the one hand, it is the electroweak presymmetry relating chiral quarks and leptons within each of their three families, as explained in Sec. 2, and their respective mirror partners denoted by tildes:

$$\begin{aligned} q_L \leftrightarrow \ell_L, \quad u_R \leftrightarrow \nu_R, \quad d_R \leftrightarrow e_R, \\ \tilde{q}_R \leftrightarrow \tilde{\ell}_R, \quad \tilde{u}_L \leftrightarrow \tilde{\nu}_L, \quad \tilde{d}_L \leftrightarrow \tilde{e}_L, \end{aligned} \quad (10)$$

with charge relations as in Eqs. (1)–(4), and similarly for the set of mirror partners. The underlying charge symmetry is hidden by the shifts produced by the topological charges of weak instantons. Regarding these, we note that the analogous of Eqs. (5) and (6) takes the form

$$\begin{aligned} \Delta Y(\hat{q}_{L,R}) &= -\frac{n_L}{3} (B - 3L)(\hat{q}_{L,R}), \\ \Delta Y(\hat{\tilde{q}}_{L,R}) &= +\frac{n_R}{3} (B - 3L)(\hat{\tilde{q}}_{L,R}), \end{aligned} \quad (11)$$

where q and \tilde{q} refer to quarks and partners in Eq. (10). The values of the topological charges demanded by the cancellation of the $U(1)[SU(2)]^2$ and $[U(1)]^3$ anomalies, and the related counterterms, are $n_L = 4$ for prequarks and $n_R = -4$ for their partners, with the correspondence $n_L \leftrightarrow -n_R$. These results match Eq. (11) to (4) for prequarks and mirror partners. Here gauge and Higgs fields are not interchanged by the presymmetric invariant transformations in the electroweak sectors.

On the other hand, there is a similar hidden charge symmetry between quarks and the partners of leptons, and between their copies, respectively:

$$\begin{aligned} q_L \leftrightarrow \tilde{\ell}_R, \quad u_R \leftrightarrow \tilde{\nu}_L, \quad d_R \leftrightarrow \tilde{e}_L, \\ \tilde{q}_R \leftrightarrow \ell_L, \quad \tilde{u}_L \leftrightarrow \nu_R, \quad \tilde{d}_L \leftrightarrow e_R. \end{aligned} \quad (12)$$

The underlying charge relations are as in Eq. (10), but interchanging $\ell_L \leftrightarrow \tilde{\ell}_R$, $\nu_R \leftrightarrow \tilde{\nu}_L$, $e_R \leftrightarrow \tilde{e}_L$. The electroweak symmetry which now interchanges the gauge and Higgs bosons with their partners requires that the corresponding coupling constants be equal.

The Z_2 symmetries of Eqs. (10) and (12) put LR symmetry into presymmetry, implying the following one:

$$\begin{aligned} q_L &\leftrightarrow \tilde{q}_R, & u_R &\leftrightarrow \tilde{u}_L, & d_R &\leftrightarrow \tilde{d}_L, \\ \ell_L &\leftrightarrow \tilde{\ell}_R, & \nu_R &\leftrightarrow \tilde{\nu}_L, & e_R &\leftrightarrow \tilde{e}_L, \end{aligned} \tag{13}$$

with the same coupling constants for electroweak gauge and Higgs bosons and their partners. This discrete symmetry, but not the two others, remains exact after the underlying charge normalization on fermions. Moreover, it extends to strong interactions for equal gauge couplings of the two color groups. A residual Z_2 symmetry then appears, which includes the strong sector, relates every particle with its partner and constrains the corresponding coupling constants to be equal, restoring parity symmetry, just as mirror symmetry in mirror matter models. Consequently, mirror symmetry can be regarded as the verifiable residual presymmetry that is requested.

Experimentally testable predictions are obtained from the LRSM or mirror matter models with Dirac neutrinos. These are the phenomenological implications of combining LR symmetry with presymmetry. In the presymmetry model, neutrinos are of Dirac type. But in the LRSM and mirror matter models, they can be both Dirac and Majorana types in principle, with Majorana neutrinos in connection with seesaw mechanisms being the more popular choices. Thus, the nature of neutrinos is one of the phenomenological features distinguishing the conventional LRSM and mirror matter models in which Majorana neutrinos are allowed and those supplemented with presymmetry in which these are forbidden.

4. Conclusions

The charge symmetries between quarks and leptons are explained by the hidden presymmetry underlying the displayed patterns. Yet, it is expanded beyond the SM in order to have an experimentally testable residual presymmetry via partial or complete duplication of standard particles — in a LR symmetric way for the purpose of restoring parity and therefore solving puzzles of the SM coherently. The doubling is implied by presymmetry apart from the ultraviolet completion of the theory, which substantiates LR symmetry. This includes the nightmare scenario with no Higgs boson.

The relation between presymmetry and LR symmetry is shown to be so robust that the experimental search for possible parity restoration through LRSM¹ or mirror matter models^{2–8} with Dirac neutrinos is a test of presymmetry. This type of neutrinos discriminates, phenomenologically, between the LRSM and mirror matter models supplemented with presymmetry and those without it in which Majorana neutrinos are not forbidden.

An experimental evidence for LR symmetry with Dirac neutrinos also mean a corroboration of the answer provided by presymmetry to one of the most intricate problems of elementary particle physics: the triplication of families. This is the result of the organizing presymmetric principles for quarks and leptons which correlates the number of families with the number of quark color charges.¹⁰

Acknowledgments

This work was supported by the Departamento de Investigaciones Científicas y Tecnológicas, Universidad de Santiago de Chile, Usach.

References

1. See, e.g., R. N. Mohapatra, *Unification and Supersymmetry: The Frontiers of Quark-Lepton Physics* (Springer, 2003).
2. R. Foot, H. Lew and R. R. Volkas, *Phys. Lett. B* **272**, 67 (1991).
3. R. Foot and R. R. Volkas, *Phys. Rev. D* **52**, 6595 (1995).
4. R. Barbieri, T. Gregoire and L. J. Hall, arXiv:hep-ph/0509242.
5. A. Y. Ignatiev and R. R. Volkas, *Phys. Lett. B* **487**, 294 (2000).
6. W. S. Li, P. F. Yin and S. H. Zhu, *Phys. Rev. D* **76**, 095012 (2007).
7. Z. Berezhiani, *Int. J. Mod. Phys. A* **19**, 3775 (2004).
8. R. Foot, *Int. J. Mod. Phys. A* **19**, 3807 (2004).
9. E. A. Matute, *Phys. Lett. B* **538**, 66 (2002).
10. E. A. Matute, *Int. J. Mod. Phys. A* **22**, 3669 (2007).
11. E. A. Matute, *Int. J. Mod. Phys. A* **26**, 3051 (2011).